# Excess light detection for greenhouse illumination control

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**Abstract:** Industrial scale greenhouses have, during the last decade, reached a high level of automation. However, the illumination is in general still controlled manually. One key factor in controlling the illumination in greenhouses is to detect how well the light energy is used for photosynthesis. Whereas too dim light means reduced production, too strong light is harmful for plants. The focus here is on finding a robust method for remote sensing of decreases in photosynthetic yield, suitable for closed loop control of the lighting in greenhouses.

## 1. INTRODUCTION

Illumination of European greenhouses consumes about as much electricity as the whole of Sweden. Modern, industrial scale greenhouses are highly automated, except for the illumination. Up till now it has not been possible to control the illumination of greenhouses because of the type of lamps used. Today, the greenhouse industry almost exclusively uses HPS lamps (High Pressure Sodium lamps), and those are not dimmable. Furthermore the spectrum of the HPS lamp fits poorly to the action spectrum of the photosynthesis. With High Brightness LEDs it has become possible to build LED lamps with sufficiently high power within a spectral distribution suitable for greenhouses. With an advanced LED lamp that combines LEDs of different colors it is possible to adjust both the intensity and the spectral composition of the illumination. Automatic control of the illumination in greenhouses could both decrease the use of energy, and improve the quality of the crop. Furthermore, the light could be used for controlling the timing of the crop.

The balance between different parameters affecting plant growth, such as light, water, carbon dioxide, nutrients, temperature and humidity, is crucial for plant health and for an efficient production of crops. Imbalance between these growth factors can lead to huge production losses. Therefore, the production in a greenhouse could benefit a lot from a well-controlled environment. The impact of a suboptimal growth environment can be demonstrated in a simple example: Wheat is grown all over the world and under widely varying conditions. The variation in crop yield is huge and the average yield of wheat is only 13% of the highest reported (Hopkins and Hüner [2009]). Although wheat is not a greenhouse crop, this example shows that losses due to non-optimal growth conditions can be enormous. The example also shows that one can gain a lot from pursuing an optimal growth environment in a greenhouse where this can theoretically be done.

One frequent problem in a greenhouse is that the light becomes too intense compared to the other growth factors and the plant's capacity to handle energy. Light energy that cannot be used by the photosynthesis is harmful for plants and induces inhibition of the photosynthesis, so called *photoinhibition*. By detecting photoinhibition early, the illumination can be adjusted, thereby avoiding excess illumination. This implies both less wasted energy for illumination and healthier plants, meaning a higher crop yield to a lower energy cost.

Photoinhibition can be detected through fluorescence from plants. Plants protect themselves from excess light through the emission of heat and fluorescence. The relation between these energy flows varies dynamically and depends on the plant's ability to cope with its environment. Fluorescence is in this way closely related to photosynthetic rate and a good indicator of plant health.

Plant stress is commonly detected by measuring fluorescence with a Pulse Amplitude Modulated (PAM) fluorometer. The PAM measures the amplitude of the fluorescence response to short duration light pulses. The technique is, however, not so useful for automatic control, since it requires a dark period of 20 minutes preceding the measurement. Also, it is very sensitive to disturbances since it measures the amplitude of the fluorescence signal and works best on leaf or very close to the leaves. To be used in practice for automatic control the stress has to be sensed remotely.

Attempts to use fluorescence for detection of plant stress in greenhouses today in a larger scale have however been done. Takayama et al. [2011] remotely detected stress in tomato plants in a greenhouse. However, their method requires dark adaption, and could only be used at night. A Dutch company, Plant Dynamics, has overcome the problem of being close to the plants by installing PAM fluorometers in a dense grid all over the greenhouse at a level of 10 cm above the plants. The information collected is not sufficient for closed loop control, since it is only measuring a few plants. Nevertheless, by using the information for retrospective analysis of growing conditions, crop production of Anthurium could be increased by 30%.

## 2. METHOD AND PRELIMINARY RESULTS

Our research is focused on finding a robust method for remote sensing of photoinhibition, suitable for closed loop control of the lighting in greenhouses.

Primarily, two different approaches are investigated. Both approaches are based on the use of an excitation signal, i.e., changes in light intensity within a specific wavelength, and the measurement of the response from the plants to the excitation signal in terms of fluorescence. The excitation signal is light from 420 nm LEDs, changing either as a square wave with a period of 10 minutes, or sinusoidal with a period of 1 minute. Fluorescence and reflectance as well as incoming light are measured by spectrometers, facing the plants at a distance of 1 meter.

The first approach is based on estimation of changes in how plants respond dynamically, measured through fluorescence, to the excitation signal. This has so far been done through the fitting of a first order transfer function with direct term to fluorescence data when the excitation signal is a step function. The rationale is that the pattern of the fluorescence induced by a diagnostic signal will differ depending on whether the plants are stressed or not.

The second approach is based on changes in the fluorescence spectra. Chlorophyll fluorescence has two maxima: one at 685 nm and one at 740 nm. The proportion between the intensity of the fluorescence emitted at 685 and 740 nm is reported to vary, depending on stress (Moya et al. [2004]). The spectral changes are recorded in the ratio between the amplitude of red fluorescence at 685 nm (RF) and the far red fluorescence (FRF) at 740 nm. The ratio is denoted RF:FRF. To overcome the problem with background light overlapping into the region of the fluorescence spectra, the fluorescence spectra is calculated as the change in amplitude of the fluorescence response to the sinusoidal excitation signal.

The two stress detection approaches are investigated through experiments where basil plants are exposed to excess light. The responses from basil plants grown under four different light treatments were compared. One set of plants were grown under low light intensity (80 µ mol photons/($m^2$ s) within PAR, the range of photosynthetic active radiation) under a LED-lamp. Another set of plants were grown under a LED lamp with the same spectral distribution but a rather high light intensity (470 µ mol photons/($m^2$ s) within PAR). Two sets of plants were grown under HPS lamps under low and high light, respectively. The light intensities, measured within PAR, were the same under the HPS lamps as under the LED lamps, but the spectral distributions differed. The most important difference between the light treatments with respect to spectra was that the HPS grown plants receive no blue light which will lead to less capacity for protection towards excess light. The HPS grown plants were therefore expected to get more photoinhibited than the plants grown under the LED lamp.

The experiments consist of four phases: one phase with the low light (80 µ mol photons/($m^2$ s)), i.e. the intensity the low light plants were grown under, to be used as a reference; one phase with the higher light intensity (470 µ mol photons/($m^2$ s)) under which the high light grown plants were grown; one phase with extremely high photoinhibiting light intensity (1800 µ mol photons/($m^2$ s)); and one phase with the low light intensity for the plants to recover from photoinhibition.

Regularly during the experiments leaves from plants were picked, dark adapted for 20 minutes and measured with a Pulse Amplitude Modulated fluorometer (PAM) attached directly to the leaves. With respect to plant stress, the fluorescence parameter $F_V/F_M$ is the well accepted and most commonly used stress indicator. As stress increases, a concomitant decrease in this parameter is observed.

One preliminary result is that the ratio between the red and far red fluorescence is decreasing with photoinhibition. The trend in this ratio closely follows the trends in Fv/Fm measured on leaf for all the experiments. The plants grown under low light under HPS lamps were the ones that got the most stressed. This is seen in both the Fv/Fm and the RF:FRF ratio. The plants grown under LED lamps and high light intensity were much more tolerant to stress than all the others. Here the Fv/Fm values changed the least and so did the RF:FRF ratio.

A direct correlation between the RF:FRF and Fv/Fm valid throughout the whole experiments could, however, not be found, since the RF:FRF turned out to be dependent also on the background light intensity with clear changes in level immediately following a change in background light intensity. Also the correlations between the RF:FRF and Fv/Fm values were dependent on which light treatment the plants were grown under.

## REFERENCES


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